NEW APPROACHES TO ENHANCE MOTOR FUNCTION OF THE UPPER LIMB IN PATIENTS WITH HEMIPARESIS

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Abstract: A common finding in patients with hemiparesis due to stroke is that they may use altered movement strategies to perform functional arm and hand movements. Altered movement strategies may be considered compensatory if they substitute the movements that are impaired at the behavioural level and yet lead to the accomplishment of the task at the functional level. Motor compensation may be maladaptive in that it may limit recovery of pre-morbid movement patterns. Studies in patients with stroke suggest that, given optimal training strategies and environments, behavioural recovery (re-appearance of pre-morbid movement patterns) may occur even in patients with chronic hemiparesis. On the other hand, it has also been shown that non-guided therapy may lead to the reinforcement of compensatory movements. The challenge facing rehabilitation professionals is to create optimal training environments based on current notions of plasticity and re-organisation in the central nervous system to maximise behavioural and functional recovery.

Key words: stroke, arm movement, compensation, recovery, virtual reality

Stroke is one of the most frequent causes of functional disability in adults [1]. In the early phases of stroke rehabilitation, therapy focuses on the minimisation of complications due to the onset of paralysis. Early interventions emphasise the maintenance of joint range and the recovery of sitting/standing balance, walking and mobility, while rehabilitation of arm and hand function receives relatively less attention. However, loss of arm motor function, which affects an estimated 30–66% of stroke victims [2], is a major contributor to long-term disability in individuals with stroke.

At the kinematic level, movements of the paretic arm are made more slowly and less smoothly compared to those made by non-disabled adults of the same age [3–5]. Patients with hemiparesis experience in-coordination between arm and hand movements during reaching and grasping [6,7], as well as in-coordination between arm-joint movements during pointing and reaching [3,8].

During the early period of recovery, in order to perform functional tasks, patients often develop atypical movement strategies to compensate for decreased control over specific joint ranges. One example of this is the compensatory involvement of the trunk during a reach for targets placed close to the body, an involvement that is only seen in healthy subjects when reaching for objects placed at distances longer than the length of the arm [6,9,10]. Our studies have shown that excessive trunk displacement is a common compensatory movement used by patients with hemiparesis for different tasks involving the upper limb. These include the transportation of the arm during arm swinging [11], whole-arm reaching [10] and the orientation of the hand during grasping [7]. Various rehabilitation approaches have been used to improve skill re-acquisition and control of the impaired arm. According to a review of 300 randomised controlled trials (RCTs) involving 2,686 patients, enhanced clinical outcomes depend on two key

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elements of training: intensity and task-specificity [12]. Intensive task-specific practice facilitates training-induced plasticity after stroke [13,14]. Better functional outcomes are also reported after constraint-induced therapy (CIT), compared to traditional (neurodevelopmental) therapies [15]. However, CIT focuses on movement outcome, rather than on the quality of motor performance resulting from repetition of increasingly difficult functional tasks [16]. Our studies and those of others have shown that repetitive task practice without therapist guidance may reinforce compensatory movements in some patients [8,17]. Detailed kinematic analysis of a reaching movement, before and after one session of repetitive practice of a pointing movement, showed that, while patients with mild-to-moderate hemiparesis tended to recover lost motor patterns with simple repetition of the task, those with severe hemiparesis tended to reinforce compensatory movement patterns [8]. These patterns were in the form of increased trunk recruitment, which occurred even in situations where such recruitment was not required for the task. We also showed that a similar increase in compensatory trunk use occurred in young children with mild hemiparesis due to cerebral palsy [18]. In this study, kinematic analysis showed that gains in arm and hand functional ability; following 3 weeks of CIT in three young children; occurred together with an increased use of the trunk during reaching.

Compensation rarely leads to efficient movement, and use of compensatory movements can result in secondary complications, such as muscle contractures and joint misalignment [19,20]. Accepting the hypothesis that compensations may retard motor recovery, we completed a series of clinical intervention studies, where compensatory movement of the trunk was limited during practice of a reaching task in patients with chronic hemiparesis. The goal of these studies was to determine the elements of a training programme for the upper limb that improve motor function and reduce compensation.

Results of studies in patients with chronic stroke indicate that physically restraining trunk movement (trunk restraint) during training can promote improvement in arm coordination patterns. In the first study, trunk restraint was achieved by attaching a modified hockey harness, worn by the patient, to a wall using an electromagnet. When the magnet was activated (trunk restraint), an immediate improvement occurred in the arm-reaching pattern. Elbow extension and shoulder horizontal adduction increased, and the interjoint coordination between shoulder and elbow movements improved [21]. The results of this study are encouraging, as they suggest that arm movement patterns can be improved with an appropriate intervention, even in patients in the chronic phase of stroke. The goals of two subsequent studies were to determine whether such changes could persist beyond the intervention period, and whether they were related to decreased arm impairment and improved function. In these studies, the trunk was restrained by two wide straps that were attached diagonally across the chest and fastened with Velcro to a straight-backed chair. In the first study, 28 patients with hemiparesis were assigned to two groups: one group practised reach-to-grasp movements during which compensatory movement of the trunk was prevented by a harness (trunk restraint), and the second group practised the same task while verbally instructed not to move the trunk (control) [22]. Kinematics of reaching and grasping an object placed at arm's length were recorded before, immediately after and 24 hours after training. Following training, the patients who trained with the trunk restraint used more elbow extension, less anterior trunk displacement and had better interjoint coordination during the reach-to-grasp task than the control group. These improvements were still evident during retention testing, 1 day later. The technique was then tested in a larger RCT [23]. In this trial, one group (trunk restraint) received progressive object-related reach-to-grasp training in a therapist-supervised home programme (3 times/week for 5 weeks), while trunk movements were prevented by shoulder belts. The other group (control) practised similar tasks with the trunk unrestrained. Clinical evaluation of the abilities and functions of the upper limb (Fugl-Meyer Arm Section and Test d'Evaluation de la performance des Membres superieurs des Personnes Agees) and kinematic analysis (trunk displacement and elbow extension in a reach-to-grasp movement) were repeated before, immediately and 1 month after the intervention. We found that training with restriction of compensatory trunk movements led to a greater decrease in impairment and improvement of function, compared with no trunk restraint. Clinical improvements in the restraint group were accompanied by increased elbow and shoulder movement and were greater in patients with initially more severe impairment. In these patients, trunk restraint decreased trunk movement and increased elbow extension, while the control group had increased trunk movement and tended to have smaller arm joint ranges. In addition, the improvements in arm function were correlated with improvements in arm and trunk kinematics.

Thus, in keeping with the results of our earlier studies, this double-blind RCT showed that trunk restraint during task-related training led to greater improvements in arm function and movement quality, while gains due to training alone were accompanied by increased motor compensation. The effects were greatest in patients with more severe motor impairments.

The results of these studies suggest that combining trunk restraint with task-related training may be an effective treatment approach to maximise recovery of reaching and grasping in patients with hemiparesis. It should be noted, however, that these studies were done in patients with chronic hemiparesis, in whom compensatory motor patterns were well established. It would be interesting to evaluate the effects of limiting motor compensations during interventions aimed at arm recovery earlier after stroke. In addition, these studies focused on only one element of a necessarily larger intervention programme for the upper limb, which would also include muscle stretching, strengthening and sensorimotor retraining. A larger RCT could be envisioned that would compare the effects of the addition of trunk restraint to usual care in a clinical setting.

Promising New Approaches for Rehabilitation of the Upper Limb

Recently, virtual reality (VR) has been used as a tool to study motor control and to evaluate and treat motor deficits secondary to central nervous system lesions such as stroke [24]. Movements recorded in VR environments are qualitatively and quantitatively similar to those recorded in physical environments, at least in a two-dimensional (2D) setting. This method is reliable to study movement in patients with hemiparesis [25], and current studies are investigating the validity of studying movements in three-dimensional (3D) environments [26].

VR is a computer-based, multisensorial, interactive simulation that occurs in real time (i.e. at the same speed as events in the physical world). Different levels of immersion can be achieved from complete 3D (BNAVE, head-mounted display) to partial 2D (computer display, TV screen). Interface devices such as a computer mouse, haptic devices, joysticks and force sensors can be added to allow the user to move in and interact with objects in the virtual environment (VE). Of crucial relevance to rehabilitation is the ultimate possibility of increasing the patient's level of interaction with the physical environment, so as to maximise their return to community life [27]. The efficacy of using VR to retrain movement and the issue of whether training in a VE will transfer to meaningful function in the physical world has been explored in a number of studies with encouraging results [24,28–34], compared to the traditional clinical settings [2].

The advantage of using VR in community, clinical and laboratory settings is that, by virtue of its programmability, environments and the amount and type of feedback can be modified according to the user's motor capacities, motivation and therapeutic goals [24,35]. For example, sensory parameters of the environment can be creatively adapted to measure responses to a larger number of situations in a shorter amount of time than is available in real-world laboratory experimental set-ups. In addition, VR environments can be especially suited to the study of how the individual can interact with moving objects. Thus, we can address questions related to dexterity and coordination that are not accessible in a real-world environment. This is of particular importance in the recovery of arm function in patients with stroke who cannot reliably use the arm and hand during interactions with the moving environment, or during dynamic interactions within a stable environment (e.g. using the arm to stabilise the body by sliding it down a railing while walking down stairs.) VR technology also permits us to study movement production in situations that, in the real world, may compromise the safety of the individual. For example, not only can we test the ability of a patient to anticipate and reach around a static or moving object, but also the task can be done without danger of incurring injury due to impact of the hand with the object. It is the manipulability of the system that allows researchers and clinicians to create situations that are motivating for the patients to engage in repetitive movements.

A current study in our laboratory incorporates a VR reach training programme to assess motor learning with functional neuroimaging, before and after repetitive reach training. Changes in functional magnetic resonance imaging signals will be correlated with measures of behavioural improvement, such as increased movement precision, joint range of motion and interjoint coordination. The VR environment that we have created simulates an array of elevator buttons and incorporates elements that have been shown to maximise learning, such as the use of motivating and challenging environments and feedback to improve performance over time.

The use of VR in rehabilitation may prove to be a valuable tool to increase the functional outcome of patients with movement disorders such as stroke.

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